BBC RD 1977/5

Engineering Research Report

The work covered by this report was undertaken by the BBC Research Department for the BBC and the IBA

Airborne television transmission

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Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION **February 1977**

BBC RD 1977/5
UDC 621.397.22

AIRBORNE TELEVISION TRANSMISSION

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Summary

Certain countries with favourable climates have already obtained satisfactory results using high flying aircraft and captive balloons to provide a rapid solution to their television coverage problems. In general, these techniques have been considered or applied in situations with no existing ground station network or where unused parts of the radio spectrum are available for broadcasting. While the United Kingdom has no immediate plans to re-engineer its very high frequency 405-line monochrome system, even at this stage, it is worth considering various methods, conventional or otherwise, that might be used to re-arrange the channelling for 625-line colour. Some of the propagation effects of transmitting from high altitude aerials have received a practical study and the results obtained are submitted as a contribution to Band III service area prediction under such conditions.

Approximate cost comparisons are made between different methods of transmission based on both capital and revenue expenditure.

Issued under the authority of

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Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

February 1977

(RA-155)

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1. Introduction

Throughout the years, broadcasting authorities all over the world have been guided by the social, economic and political factors that prevail within their country, when starting a television service. Also the type of transmitting equipment available at the time of initial planning tends to dictate the way in which any network will evolve. The developing countries are of course, at an advantage here and it is therefore not surprising that for general coverage purposes the question of non-conventional transmitting techniques has been considered, especially for educational programmes. The viability of airborne television transmitters in certain circumstances has been confirmed largely as a result of experimental work conducted in America by the Westinghouse Electric Corporation. In the early days, their work was based on the use of high flying aircraft but more recently tethered balloon systems capable of operating between 10,000 and 15,000 ft* have been perfected and marketed as an alternative solution for obtaining extensive service areas quickly.

However, provided airborne television could be co-ordinated with existing ground systems, the concept need not necessarily be confined to people with unused spectrum at their disposal and who require a service for the first time. The idea of augmenting airborne and ground stations underwent close examination in 1961 when a Douglas DC-6 aircraft, flying over Indiana and Ohio at 23,000 ft, successfully transmitted an educational television service using the higher-frequency part of Band V. The experiment in "Stratovision" systems lasted for three years, and hundreds of schools participated, but in the case of America, the Federal Communications Commission deemed that it would not be in the best interest of spectrum allocation to recommend permanent operation.[1,2]

The possibility that similar systems may be applicable elsewhere has now been taken up by the European Broadcasting Union and certain member countries are involved with feasibility studies embracing both airborne transmission and satellite broadcasting. In the German Federal Republic an investigation has been made on a plan in the 12 GHz band, based on a specially designed aircraft flying at around 60,000 ft and the French have expressed an interest in captive balloons. While the BBC has no immediate plans for domestic transmission by using anything other than the established methods, the need to re-engineer Bands I and III for 625-line colour gives the subject greater importance.

The work contained in this report examines the possibility of using conventional civil aircraft, suitably modified, to serve the United Kingdom with v.h.f. television. Aircraft could be used either as an interim measure to help convert existing 405-line ground-stations to 625-line colour transmission or provide a permanent solution giving two-programme national coverage. The choice of frequency band becomes important; if channels in the upper part of Band III are assumed, then maximum apparent terrain roughness is achieved and the amplitude of any reflected signals duly attenuated. Thus, in a situation where aircraft movement causes ground reflections near the viewer's aerial to vary in phase relative to the direct wave, least disturbance to the picture would occur.

2. Theoretical analysis

Due to the extreme height of the transmitting aerial, when compared to a normal terrestrial system, the transmitted signal will of course cover a much larger area. Also screening by hills, trees or buildings will not be so pronounced except at the edge of the service area where the angle subtended between the horizontal and the airborne transmitter is small. On the other hand, a problem could arise due to the airborne transmitter not remaining stationary over a fixed point, but travelling in a circle.

Before looking further into the effects of a moving transmitter, it is necessary to consider the simple case, where a fixed transmitter radiates over a smooth earth (see Fig. 1). The ground reflected signal has obviously travelled a slightly greater distance than the direct signal and the path difference determines the relative phase. Depending whether the two signals add roughly in phase or tend to cancel, the resultant signal is greater or less than the direct signal component. When two equal amplitude signals are exactly 180° out of phase they cancel one another. In practice, the minimum field strength falls by no more than 30 dB below the direct signal and in many cases the difference is less than 10 dB. This is due to the reflection coefficient of the ground affecting the amplitude and phase of the reflected signal.

The reflection coefficient is determined by three

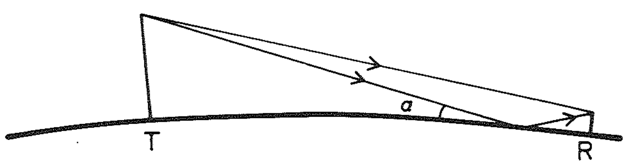


Fig. 1 - Propagation over smooth earth

* In view of the current practice of using feet to give aircraft height, all transmitting heights in this report are given in feet rather than SI units.

main parameters:

(i) the electrical properties of the ground at the reflection point
(ii) the angle, α in Fig. 1
(iii) the polarisation and frequency of the transmitted signal.

If these are known it is possible to calculate the reflection coefficient and then the resultant field strength. Fig. 2 shows how this field strength varies with distance when vertically and horizontally polarised transmitting aerials are flown at 26,000 ft and signals are received 10 metres a.g.l.

It is apparent that a vertically polarised wave produces smaller field strength variations than a horizontally polarised wave and so would be recommended in any final system. Even then minima of at least 10 dB would occur at distances of 50 km or more from the transmitter, and a receiving aerial could be badly positioned in a relatively low field. Should such a situation arise, then, by simply altering the receiving aerial height thereby changing the path difference, the field strength could be substantially increased.

Returning to the situation where the transmitter is in a moving aircraft, it becomes obvious that there will be many cases where the received field strength is continually rising and falling due to the changing distance between transmitter and receiver. Thus, with the vertical polarisation example given in Fig. 2 using an aircraft flying a circle of 5 km radius at 314 km/h, the received field strength would cover a range of about 10 dB once every 6 minutes, where the mean aircraft to receiver distance is 52 km. This in itself would not present a problem to a receiver with good a.g.c. but where the minima are more closely grouped (i.e. higher receiving aerials or lower transmitter to receiver distances) the fluctuations due to aircraft movement could be much more frequent and the effect might become visible on the received signal, despite a.g.c.

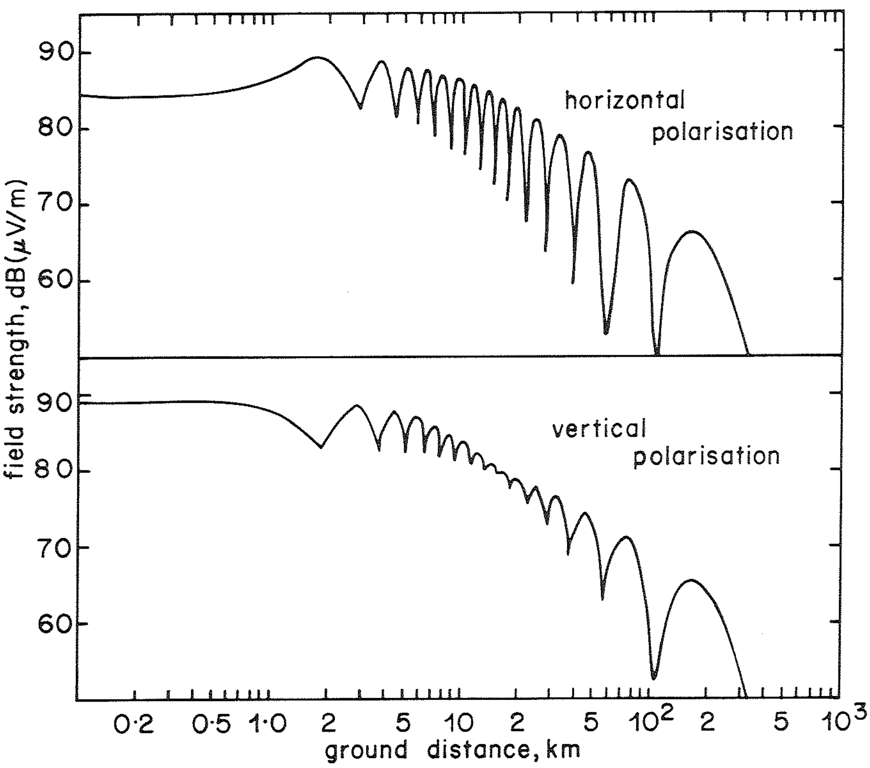
Picture degradation could also be caused by positions of minima varying with frequency and the sound to vision ratio could well depart from the nominal value by several decibels. However, it is estimated that a typical "tilt" across a 6 MHz channel would be no more than 3 dB, especially when the vertical radiation pattern, (v.r.p.) of the receiving aerial is taken as a contribution towards reducing the level of foreground reflections.

Fig. 3 shows the calculated field strength variation for a vertically polarised signal transmitted from 10,000 ft, the polarisation and height chosen for tests. The calculation assumes a nominal effective radiated power, (e.r.p.) of 1 kW over a smooth curved earth having a ground conductivity of 10 mS/m and a dielectric constant of 4, both values being typical for the United Kingdom.

3. Airborne transmission tests at 224 MHz

3.1. Purpose of experimental work

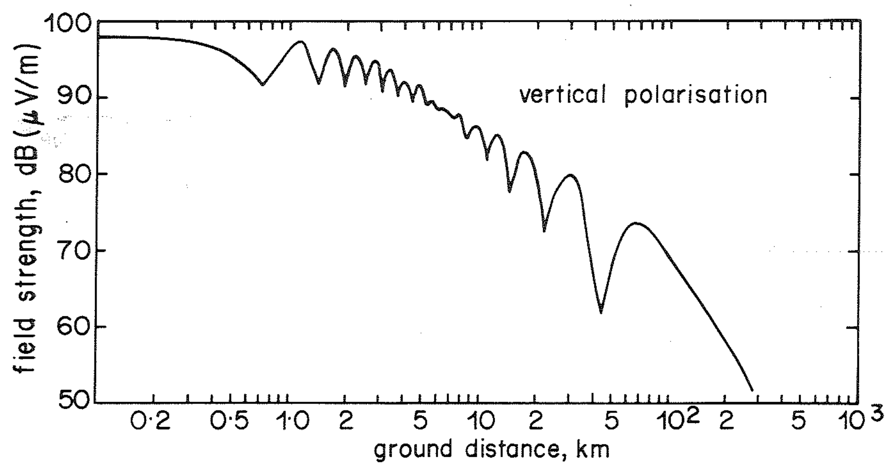
In order to investigate the propagation of Band III signals from high flying aircraft it was originally proposed



Calculations assume:

i) isotropic sources
ii) ground constants $\epsilon = 4$, $\delta = 10$ mS/m
iii) a smooth curved earth with 4/3 true radius
iv) 1 kW e.r.p.
v) frequency = 224 MHz

Fig. 2 - Calculated field strength variations for a transmitter height of 26,000 ft and a receiving height of 10 metres a.g.l.



Calculations assume:

i) isotropic source
ii) ground constants $\epsilon = 4$, $\delta = 10$ mS/m
iii) a smooth curved earth with $^4/3$ true radius
iv) 1 kW e.r.p.
v) frequency = 224 MHz

Fig. 3 - Calculated field strength variations for a transmitter height of 10,000 ft and a receiving height of 10 metres a.g.l.

to carry out a series of tests at 23,000 ft, but aircraft limitations and airspace restrictions prohibited flying above 10,000 ft. Nevertheless, it was thought that if the field strength measured from a transmitter at 10,000 ft agreed with the theoretically derived curves, then it would be reasonable to assume that similar theoretical curves, for 20,000 ft or higher, would also apply in practice.

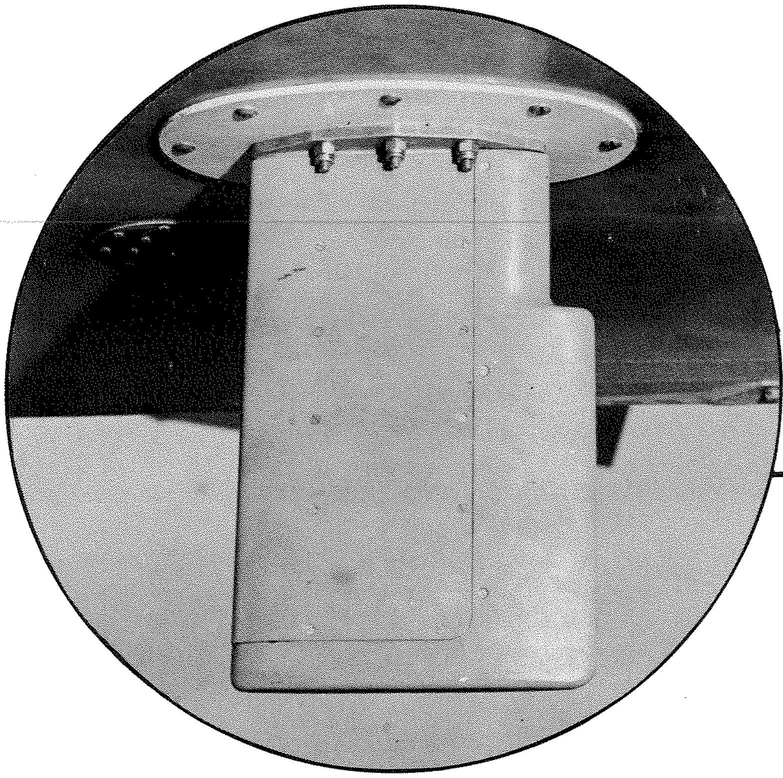
An out of band frequency of 224 MHz was used for the tests since this would avoid interference to existing Band III television services.

3.2. Equipment

An Auster pictured in Fig. 4, belonging to the Royal Aircraft Establishment at Farnborough (RAE) was used to carry the transmitting equipment. The merits of using this aircraft were a relatively low flying speed which would give time to adjust the measuring equipment on the ground and the fact that it could readily carry, attached beneath the fuselage, an active aerial with a near omni-directional horizontal radiation pattern (h.r.p.) which had been developed at the RAE.

This active aerial was in the form of an aerofoil section and contained a transistorised power amplifier with the aerial itself running along the trailing edge, (Fig. 5). Being an integrated assembly, it was not possible to measure the radio frequency power going into the aerial, but by noting the d.c. input to the power amplifier and applying an assumed efficiency, the energy into the aerial should have been about 1 watt. In any case it was not essential to know the absolute power since the object of the test was to measure the range of maximum to minimum field strength. With the availability of the RAE equipment it was only necessary for BBC Research Department to construct a simple crystal controlled drive oscillator. Details of the transmitting equipment and

Fig. 4 - Mk. IX Auster used for flight trials



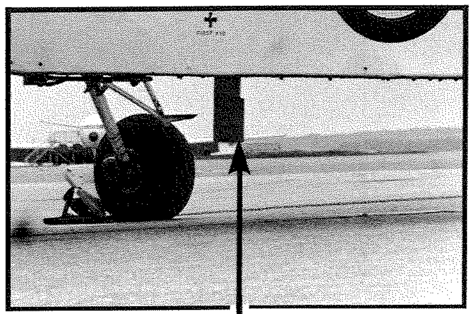


Fig. 5 - Active aerial mounted beneath fuselage of Mk. IX Auster

flight path profile are summarised in Appendix I. The field strength measuring apparatus comprised a five-element log periodic aerial mounted at 10 metres a.g.l., a receiver and a pen recorder.

3.3. Flight trials

As far as possible, the aim was to fly a straight course at 10,000 ft. Measuring equipment was positioned at intervals along the flight path and the field strength recorded as the aircraft approached and passed overhead. A radio-telephone link with the aircraft enabled the pilot to report his position so that transmitter to receiver distances could be related to the chart recordings. It was arranged with the RAE that the aircraft would take off from Farnborough, and fly south westerly towards Lyme Bay on the Dorset coast. BBC measuring equipment was located at Farnborough and Lasham, the latter being approximately 20 km from Farnborough. The IBA were also to make similar measurements with equipment stationed further along the flight path near Winchester and Salisbury.

During the first flight on 16 April 1975, the signal strength observed was well below that anticipated and the flight was cancelled. After checks on the transmitter alignment, the main flight took place on 23 April 1975. Although still below expectations, the radiated transmitter power was adequate to provide useful measurements. The flight was therefore completed since it would have been difficult for various operational reasons to arrange further flights with an improved transmitter. On the outward run performance limitations and a 28 km/h tailwind prevented the aircraft from reaching 10,000 ft until it had covered 74 km which meant that the field strength recordings made at Farnborough and Lasham were difficult to relate to theoretical curves based on a constant height. Unfortunately, the IBA receivers suffered from both frequency drift and low sensitivity, although neither problem would have mattered had the transmitter been radiating at full power. Wind conditions were more favourable on the return flight and the aircraft passed over Lasham at 10,000 ft maintaining height until about 16 km from Farnborough. Consequently the field strength recording made at Lasham proved to be the only one to yield useful results.

Part of the Lasham chart is reproduced in Fig. 6, and Fig. 7 shows the same results plotted on a logarithmic distance scale compared with the theoretical variations for 1 watt e.r.p. It will be seen that a transmitting aerial height of 9,500 ft has been used for calculating the field strength because the Lasham receiving site was approximately 500 ft a.m.s.l. The surrounding area was fairly flat with the reflection point never more than 330 metres away and so the foreground was also assumed to be about 500 ft a.m.s.l.

3.4. Outcome of flight trials

From Fig. 7 it is obvious that the power radiated from the test transmitting aerial was only of the order of 1 mW and regrettably it was impossible to measure all the way to the radio horizon. In spite of low power, signals were measured over a substantial part of the flight path and valuable experimental data obtained to assist the prediction of reflection coefficients at uncluttered

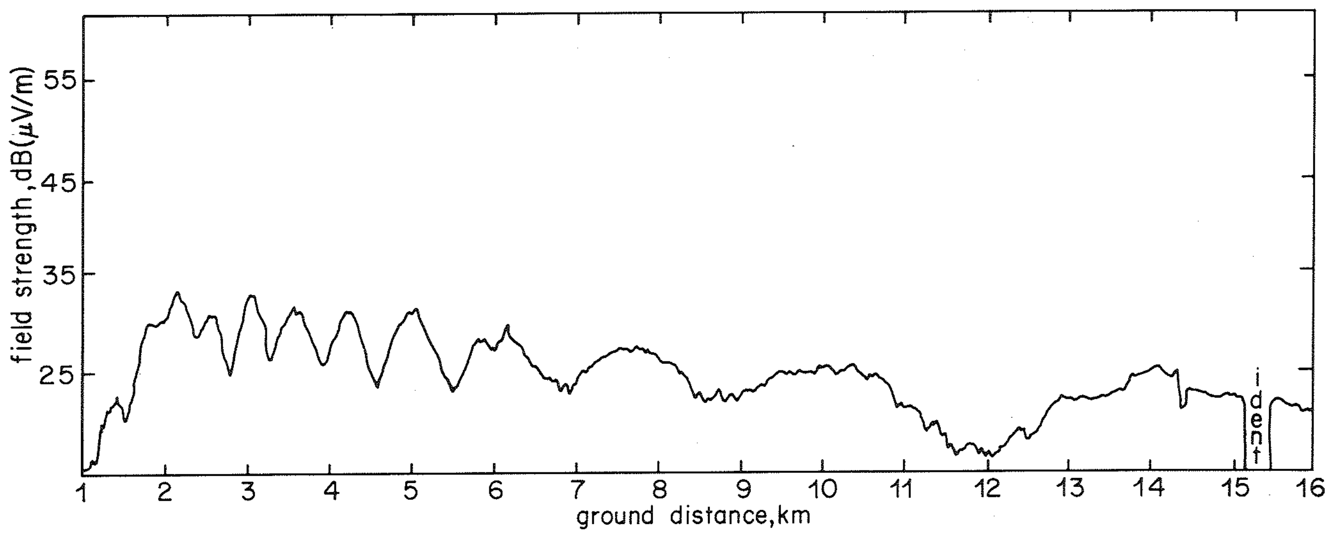
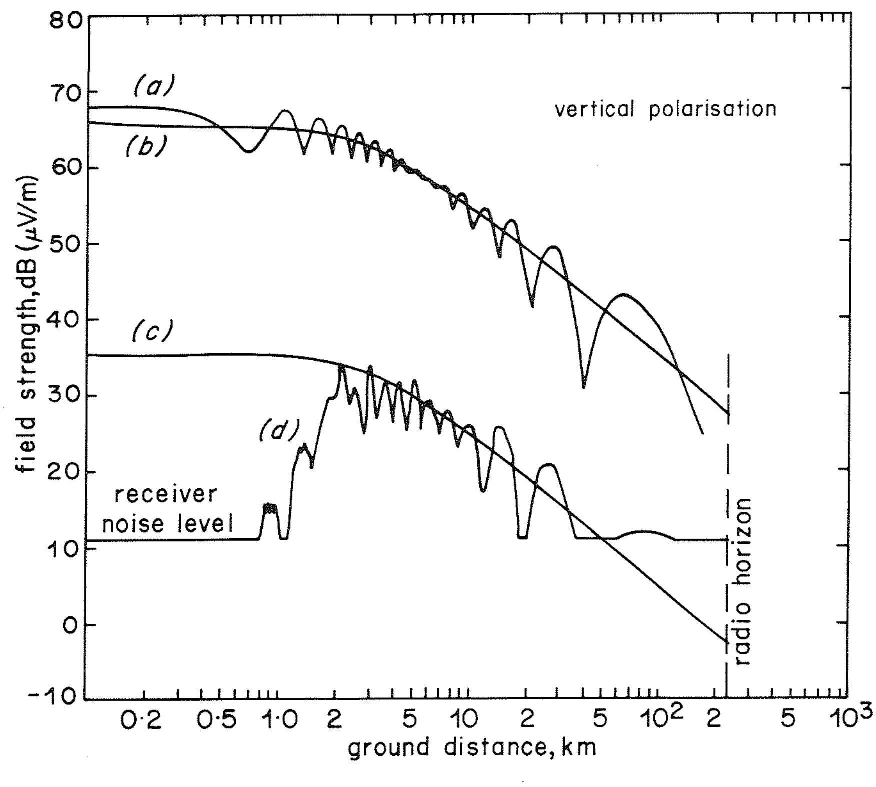


Fig. 6 - Aircraft altitude = 10,000 ft a.m.s.l.
Field strength/distance chart recording made at Lasham Receiving Site

receiving sites.

The calculated field strength/distance curve applies only when the reflecting surface is smooth, but because the transmitter is very high, the effect of surface roughness may be significant. For instance, at aircraft ranges of 3 km to 10 km, where the indirect wave has an angle of incidence approximating to the Brewster angle, the reflection coefficient should go through a minimum resulting in a decrease in the field strength variation. At Band III, the average surface roughness between these ranges would have to be less than 20 cm to be considered free from perceptible irregularities[3] (see Appendix II). Since the terrain around the Lasham site has surface undulations greater than 20 cm, it is not surprising that the variations on the chart recording at 3 km to 10 km are greater than the theoretical



(a) Calculated field strength for 1 watt e.r.p.
(b) Free space field strength for 1 watt e.r.p.
(c) Free space field strength for 1 mW e.r.p.
(d) Measured field strength at Lasham receiving site

Calculated curves (a), (b) and (c) assume:

i) isotropic sources
ii) ground constants $\epsilon = 4$, $\delta = 10$ mS/m
iii) a smooth curved earth with $^4/3$ true radius

Fig. 7 - Calculated and measured field strength variations for a transmitting height of 9,500 ft, a receiving height of 10 metres a.g.l. and a frequency of 224 MHz

curve might suggest, but the variation does go through a minimum, being at most ranges of similar amplitude to the calculated values. The results fully justify the choice of vertical polarisation for a more constant field. Even at greater aerial heights, where the theoretical reflection coefficient is less likely to apply due to the increased "smoothness" requirement of the ground, the theoretical curves should give a good indication of practical field strength variations with flight movement and distance.

The absence of measured field strength as the aircraft passed over the receiving site was mainly a consequence of the receiving aerial v.r.p. (The v.r.p. of the transmitting aerial was substantially omnidirectional towards the ground). Throughout the tests the angle of elevation of the receiving aerial was zero, so that when the aircraft was nearly overhead the gain was about 20 dB below the maximum.

In a practical viewing situation when the aircraft was directly overhead, changes in field strength due to the radiation pattern of the receiving aerial could be made negligible. For the flight pattern quoted in section 1 a typical Band III yagi, pointing upwards, in the direction of the aircraft, should produce an almost steady signal at the receiver. By simple geometry a circle of 5 km radius at 8 km altitude forms an inverted cone with a vertex of $\pm 32^{\circ}$, an angle well within the half power beamwidth of a three element aerial.

4. Airborne television as an aid to VHF re-engineering

4.1. An outline plan for the United Kingdom

To derive the best general coverage in the main centres of population, it is desirable that such places as London, Birmingham, Bristol, Cardiff, Manchester, Edinburgh and Glasgow all fall well inside the limits of service.

For complete coverage it would still be necessary to operate a few ground relay stations. These could be kept to a minimum when selecting the flying zones, by satisfying two main criteria in areas particularly susceptible to large shadow losses. Firstly, angles of reception above the horizontal should be as high as possible in the mountainous and densely populated areas of industrial South Wales and secondly a two-transmitting-station "crossfire" plan should be used to cover the Pennine valleys, thereby illuminating both north and south facing slopes from opposite directions. It is also desirable to confine the service to the target area and restrict the level of signal falling outside. The use of directional transmitting aerials should therefore be considered, with appropriate reduction in e.r.p. towards the continent.

Another factor in preparing the basic specification is to decide whether to modify an available aircraft which may be lacking in ceiling and flight duration, or to have one specially designed to meet the needs of airborne broadcasters. Clearly, unless there is likely to be a demand for a number of airborne transmitters, the latter course could prove uneconomic and for the plan to be discussed, the Bristol Britannia has been chosen as representative in being able to meet requirements. By carrying sufficient fuel, "turbo-prop" airliners like the Britannia can maintain an operational altitude for about eight hours and still have two hours reserve with which to arrive on station and return to the base airport.

Having taken coverage and flight performance into account, it becomes apparent that to obtain a near line-of-sight path over the area in question, two suitably stationed Britannia aircraft would need to transmit from around 26,000 ft, a height approaching their ceiling. To allow for atmospheric refraction, Fig. 8 shows range versus altitude for two values of earth's radius modified by a factor K = 1·33 and K = 1·2. While the standard K = 1·33 still gives a useful approximation, it may slightly over-estimate the distance to the radio horizon. The range however, is unlikely to fall below that indicated by the dashed curve (K = 1·2), taking into account available data on the mean refractive index gradient up to 26,000 ft. The curves give the horizon distance for differing values of aerial elevation and at 26,000 ft, a television coverage range of 348 km to 367 km would be a practical possibility. If the majority of people are to be served, it is essential that the plan employs more than one aircraft. So each must be capable of operating at the specified altitude with an equivalent flight duration and have transmitters of similar e.r.p., tunable to either of the two channel groups. Otherwise, any routine exchange of an unserviceable aircraft for a standby would become difficult and, in an emergency, almost impossible.

One way of dealing with the numerous propagation and aeronautical constraints would be for one transmitter to be stationed over Somerset and another over Angus, each flying in a circle of about 5 km radius. Alternatively, to provide greater crew comfort, they could fly a "race track" pattern at holding speed (minimum drag airspeed) with the major axis no greater than 10 km in length. This would give the pilot an opportunity to fly straight and level and so re-set his instruments occasionally.

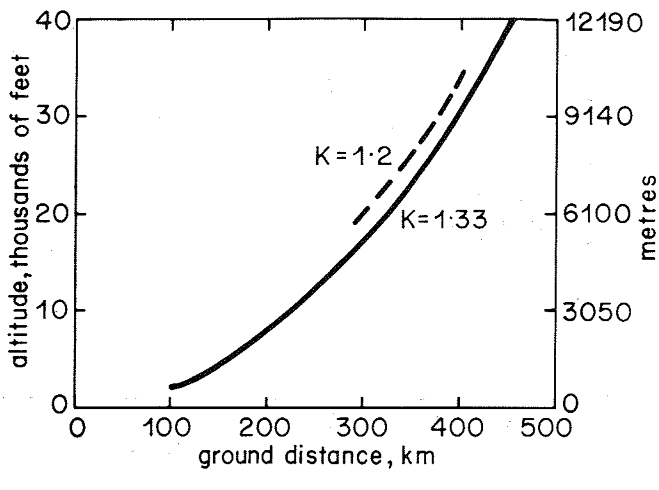


Fig. 8. - Horizon distance versus altitude for earth radius modified by factor K

Consideration has been given to a transmitting aerial which has directivity in both horizontal and vertical planes. One problem associated with the application of any such directional array is the need to maintain positional stability, irrespective of aircraft heading and altitude, but this is not insuperable. Moreover, it may be justified to ensure an economic coverage, particularly if, by using horizontal directivity the service area is confined to viewers in the United Kingdom. It could also be deemed more acceptable to the aviation authorities, if the transmitting flight zone was to one side of the country rather than centrally located in the main air lanes.

4.2. Service area prediction

For calculation purposes, the Somerset and Angus transmitting stations are each equipped with an aerial having the same radiation characteristics. Alignment of the h.r.p. shown in Fig. 9 is for greatest radiation towards the north-east and south-west respectively. The e.r.p. in azimuth has been derived by applying a unit field of 28 kW in the direction of maximum radiation. A slightly modified pattern to the rear of the diagram would provide better coverage to Cornwall and N.E. Scotland, but depending on the tolerance of any final system, it may have the undesirable effect of spreading the service into France. The limit of service contours are for the flight conditions described in section 4.1. and correspond to a free-space field of 70 dB (μV/m) at the radio horizon. Assuming the use of high channels in Band III, an estimate of the combined loss figure for average terrain, anti-phase ground reflections and clutter, with receiving aerials 10 metres a.g.l. near the radio horizon, is around 15 dB. This overall factor is thought to have a constant value, because under conditions giving high terrain and clutter loss, the effective surface roughness increases, thereby tending to reduce the amplitude of any destructive foreground reflection. Hence a field strength of 55 dB (μV/m) would then be available to the fringe viewer at limits shown by the full lines in Fig. 10. This field-strength, according to CCIR recommendations 417-2 paragraph 1, is the minimum median level that a broadcasting authority can reasonably expect to remain protected against foreign co-channel interference for 95% of the time.

4.3. Co-channel interference

To determine the theoretical distance at which a channel used for airborne transmission can be re-allocated requires reference to the way field strength decays with distances beyond the radio horizon. Regardless of whether the interfering transmitter is an airborne or ground station, any plan must arrange for a certain minimum spacing between the unwanted source and the nearest co-channel receiving location.

Fig. 11, in addition to providing data for service area limits using different levels of e.r.p. (e.g. a wanted 55 dB (μV/m) contour for 2·8 kW occurs at the same range as 65 dB (μV/m) for 28 kW on curve (a)), also shows as curve (b) a simplified field strength/distance prediction exceeded for about 5% time out to 1000 km.

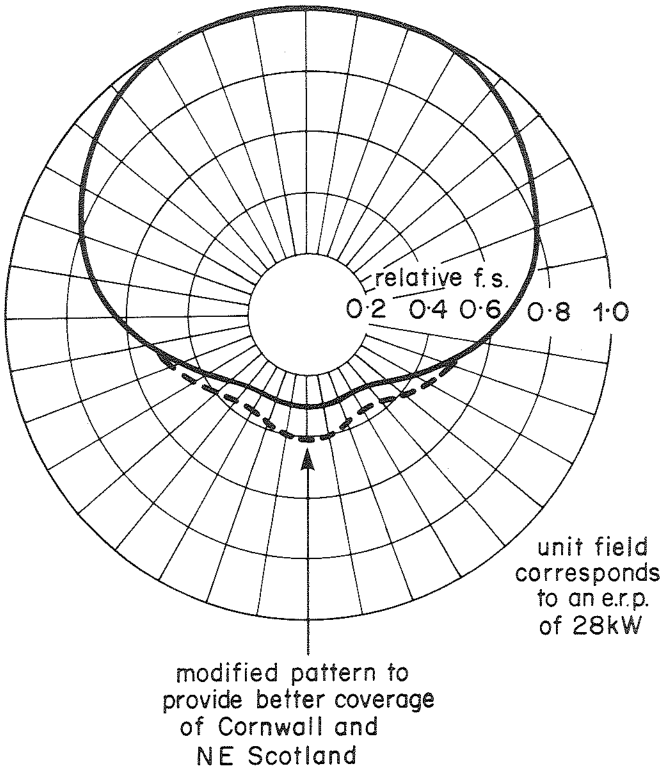


Fig. 9 - Horizontal radiation pattern of Band III transmitting aerial

Aerial consists of 4 tiers of vertical dipoles mounted on a metal pole

Curve (b) approximates at the greatest range to a tropospheric scatter calculation in the diffracted region.[4] At shorter ranges (450 to 700 km) the curve is based partly on CCIR propagation curves and partly on an effective earths radius which, from limited meterorological evidence, would apply for 5% of the time, assuming the rate of change of refractive index is uniform for the whole path and independent of height. Little is known about field strength/time behaviour when transmissions from aerials situated high above any inverted tropospheric layers are received near ground level. Furthermore the proportion of time during abnormal propagation, for which signals would be stronger or weaker than indicated by the established empirical curves, is far from certain. Setting aside this deficiency in our understanding of propagation over the type of path under consideration, it is possible to establish a minimum distance between the transmitting aircraft and nearest co-channel viewer.

The planning ratio to avoid objectionable interference between wanted and unwanted 625-line television signals, having the same nominal carrier frequency, is 45 dB. This is the CCIR protection ratio acceptable for 1% to 10% of time in terrestrial services in which interference normally has a large fading range and variability. We will ignore the beneficial effect of vision frequency line-offset, receiving aerial discrimination and terrain loss, any of which could reduce the ratio to less than 30 dB, so the calculation will cater for the worst case. Paragraph 4.2. has already stated that 55 dB (μV/m) is the minimum

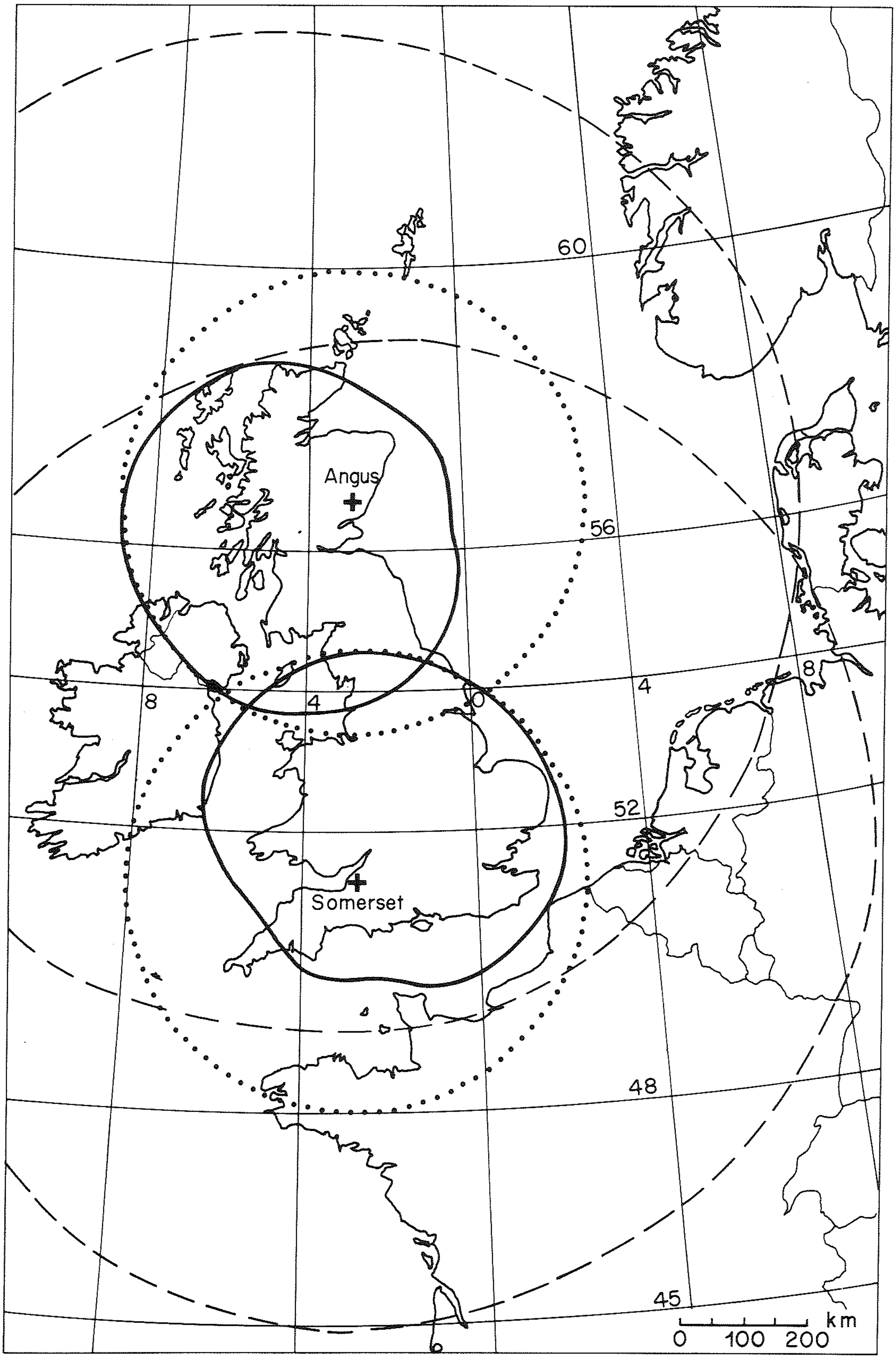


Fig. 10 - Band III coverage using two identically equipped aircraft at 26,000 ft

55 dB (μV/m) limit of service
10 dB (μV/m) interference distance
Radio horizon

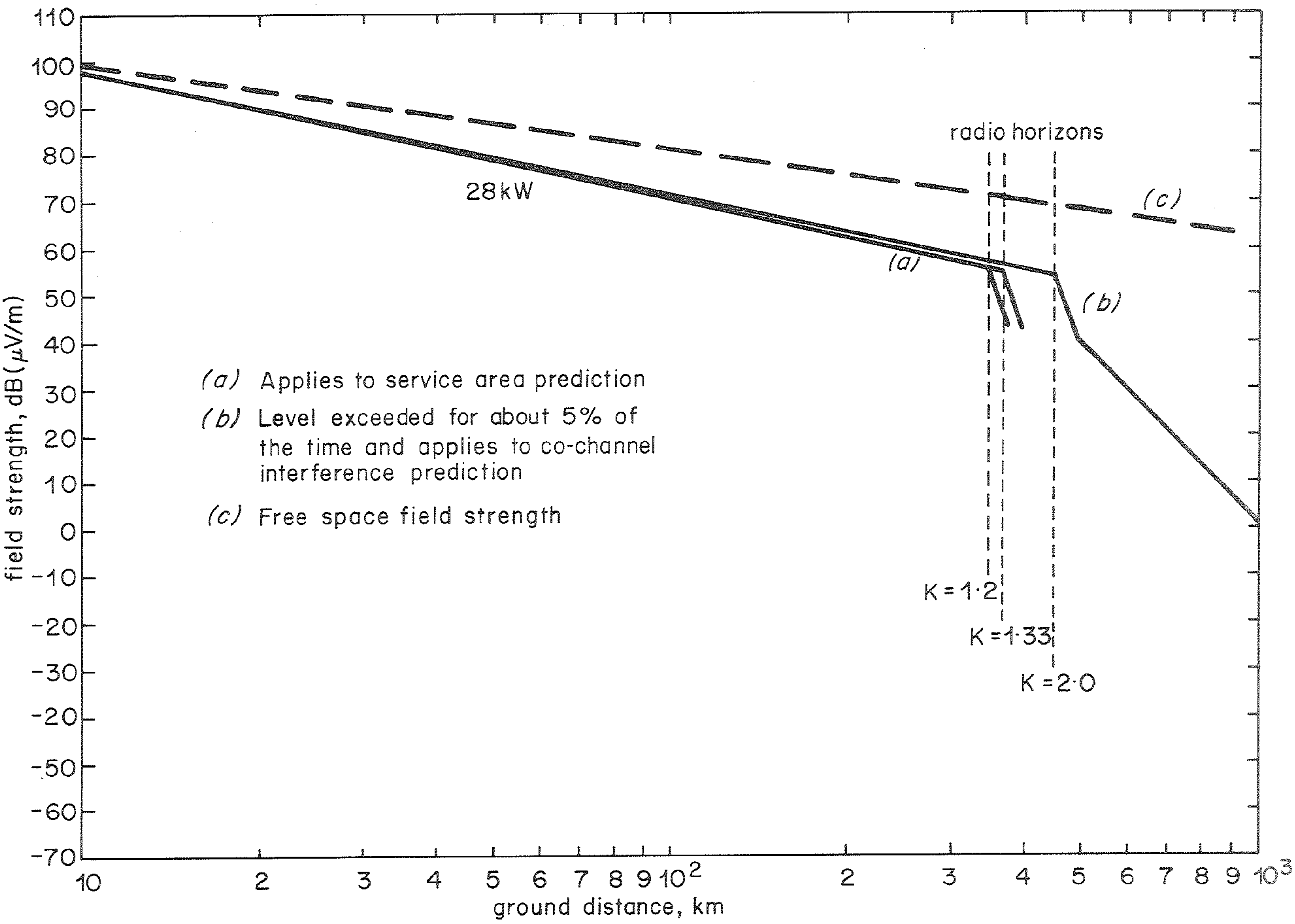


Fig. 11 - Simplified field strength versus distance prediction for 26,000 ft transmitting aerial height at 50% of locations

level that can be reasonably protected against interference for 95% of the time. Hence the greatest level of unwanted signal must not exceed 10 dB (μV/m). From Fig. 11 it is predicted that for a suggested maximum e.r.p. of 28 kW the field would have fallen to the value of 10 dB (μV/m) at a distance of 860 km and by taking account of the directional aerial h.r.p., Fig. 10 shows the interference areas bounded by the broken lines. It is also pertinent to note how this interference distance only falls by 205 km if the e.r.p. is reduced by some 14·5 dB to 1 kW; indicating that the value of a directional transmitting aerial is not nearly as effective as might be thought when protecting co-channel services operating well beyond the radio horizon.

To derive the minimum distance between airborne transmitting stations at 26,000 ft, the planning engineer should arrange to repeat a channel in the usual lattice configuration, and simply add the service area distance (367 km) to the interference distance (860 km) to give a total separation of 1227 km. For outline prediction purposes a figure of 1200 km would seem a fairly safe guide for any basic network calculations.

4.4. Channel allocations

Clearly with the Britannia's maximum flying height restricted by certain performance limitations, it would be necessary to employ two aircraft to provide a national replacement v.h.f. programme. It would therefore be necessary to allocate a total of four channels so that both stations may transmit a BBC and IBA service simultaneously, without mutual interference. It is the Somerset channels that would seriously affect Eire, France, Belgium, Holland and West Germany, with Angus also causing interference to Eire plus the coastline of Scandinavia and continental Europe. To complete the investigation on frequency choice would require detailed consultation with all concerned. Perhaps by making far more efficient use of the v.h.f. spectrum with airborne techniques and causing a serious interference problem on only two channels to most of our neighbours, it may be possible to agree some form of international plan. Alternatively, the satisfactory integration of an airborne system with operational ground stations could prove too difficult. Any reduction in channel requirements brought about by using a single purpose-built aircraft would be of little advantage, because flying at 48,000 ft in order to maintain the same coverage would result in an equally difficult co-channel problem. One way of virtually eliminating a severe international interference situation would be to operate just a single Britannia over Angus as reduced

height. Such an arrangement would serve a substantial number of people in the northern half of the United Kingdom and also overcome the well known difficulties of developing programme distribution and coverage networks for scattered communities in the Highlands and Islands using ground stations. Any resulting co-channel signals would be mainly domestic in origin and could be taken into account when re-engineering existing ground transmitters in Wales, Northern Ireland and the southern half of England, although consultation with Eire would be necessary.

5. Discussion

5.1. Cost comparison: Ground stations with aircraft transmission

A financial comparison with ground station re-engineering has been based on typical operating figures for the Bristol Britannia turbo-prop airliner. Appendix III gives details of a cost breakdown and includes all the main items of hardware and running expenses. Table 1 summarises both the capital and revenue totals for the cost to a single organisation if a re-engineered two programme network was shared equally between two broadcasting authorities, while Appendix IV gives a near complete financial comparison between all broadcasting systems, including satellites. However, it should be realised that the aircraft costs under the v.h.f. column, may be considerably less than certain estimates made by other countries because ours are based on an available out-of-date airliner rather than a specially designed flying unit.

TABLE 1

Financial Summary

System	Capital	Revenue (Expenditure)
Aircraft	£M 0·88	£M 1·54
Ground (UK re-engineering)	£M 4·5	£M 0·2

In terms of capital expenditure the use of aircraft would give an estimated 80% saving and this could be greater if the need to radiate new v.h.f. parameters caused more of the existing transmitting station aerials to be replaced than currently envisaged. The largest single item of revenue saving on closing the ground network would be public electricity supply costs, as virtually all buildings and mast facilities must remain to accommodate the u.h.f. television and f.m. radio services. Applying the estimates tabulated herein the annual cost of using aircraft instead of ground stations, would require seven and a half times more revenue. It is apparent that an economic comparison between the two methods is very dependent on the length of time over which the service is operated, as well as interest rates and changes in fuel prices. Since the total of revenue and capital costs is roughly the same over a period of three years it follows that the aircraft solution would only be attractive in the short-term, and that as far as the UK is concerned, the conventional method is more economic in the long term, i.e. for periods greater than about three years.

There are two final topics for discussion which fall outside the scope of this report and would require individual appraisal at a time when re-engineering for 625-line colour transmission became more imminent. Firstly, the number of staff needed to operate and maintain a revised v.h.f. network would depend very much on the degree to which the latest technology ground stations could be left unattended. If aircraft were chosen, then to a first approximation, the number of staff currently involved with 405-line stations would be about right to form an engineering flying unit. Consequently staff costs would tend to balance out in the comparison that has been made and so do not appear in Appendix III.

Secondly, the vast majority of viewers would have to purchase a new v.h.f. receiving aerial and the overall expense to the public could vary considerably. For example, with ground stations, the total domestic aerial bill for the nation would depend very much on how the Band I and Band III channels were allocated relative to area population density. The planning engineer would have to bear in mind that some viewers may once again require an aerial for both v.h.f. bands and it would be desirable to restrict such a situation to areas of low population. By using airborne transmission, the field strength distribution over the United Kingdom would tend to be fairly even and most receivers would give satisfactory results using a single medium-gain Band III aerial. Instances where each ground station service area is inclined to give extremes of high and low field would disappear and the demand would be for a uniform aerial design with sufficient bandwidth merely to cover the top four channels in Band III. By reducing the range of aerial designs on the market, it would probably be possible for manufacturers to economise and cut their retail costs.

5.2. Advantages and disadvantages of airborne television

While in terms of capital outlay the use of an airborne transmitter may appear financially attractive and in return gives almost total coverage when commissioned, any concept of regional or local television broadcasting would have to be abandoned. Even so, by employing the two station plan a small degree of area content could always be introduced by feeding separate Northern and Southern programmes to the Angus and Somerset ground control stations. One method of programme feed from each ground control would be to site a conventional s.h.f. link beneath the flight path. The need for some form of automatic aerial tracking to keep the aircraft within the microwave beam could be eliminated by taking advantage of the short transmission distance and using fairly low

gain aerials with near omni-directional radiation patterns. Engineering talk-back and transmitter performance telemetry could also be sent over the same link.

Any comparison between airborne and ground transmitters must cover the question of relative reliability. A failure in the proposed airborne system is bound to affect at least half the country and the duration of a "shut-down" could run to several hours. Even with a third aircraft on standby budgeted for in Appendix III, it could be some time before it was on station to relieve the faulty equipment. Bad weather conditions could also delay take-off and upset programme schedules, but deployment of aircraft landing places in conjunction with meteorological forecasts could help to avoid such circumstances. Mention has already been made of an experimental educational service using a DC-6 and in their report the operators explain how the availability of programme was maintained for 98·7% of the time for the year of best performance. This record is most impressive, bearing in mind all the things that could have gone wrong, but would have produced a far greater audience disturbance than a single ground transmitter having a similar outage time.

The relative merits of both systems are summarised in Tables 2 and 3.

5.3. Balloons as an alternative to aircraft

The use of captive balloons as a means of increasing reliability certainly merits investigation. Again it has been the work of the Westinghouse Electric Corporation that has received study and in particular their subsidiary, Tethered Communications (T.COM.). It is claimed that for broadcast periods up to 24 hours a day, a single balloon system can achieve better than 99·9% availability. The initial testing and assembly work was carried out in the Bahama Islands off Miami, Florida. Until practical experience has been gained in northern latitudes where winds speeds in excess of the 190 km/h working limit are sometimes encountered, it is difficult to estimate how many occasions high winds would prohibit flying, especially in the more exposed parts of Scotland. According to the makers, the prototype model continued to function throughout a hurricane blowing at 150 km/h with squalls of more than 180 km/h (force 12 Beaufort wind scale). It is evident from the applications information supplied by T.COM. that balloon equipment is aimed at use in developing countries where no conventional ground station network exists. Under these conditions the system is ideal and caters well for community viewing in transportable receiving auditoriums that are supplied as part of an entire broadcasting package.

The commercial approach to the Balloon or Aircraft decision is interesting. Regardless of the apparent success of the "Stratovision" experiment, further development in the field of extra-high transmitting aerials seems to have favoured the captive balloon rather than pursuing any aircraft system to a more sophisticated degree. Consequently, it can only be assumed that every facet of the problem has been assessed and on balance a balloon is seen as the best method for any future long-term sales promotion. To obtain an equivalent United Kingdom coverage with balloons at 13,000 ft rather than aircraft at twice the height, much of the same propagation theory would apply, including changes in field strength with shifts in balloon position. Because of the lower operating height comparable coverage would require three stations rather than two and assumes that the fringe viewer would use both a high gain aerial plus masthead pre-amplifier. As the provisional cost of three double channel T.COM. equipments has been quoted at between £M 5.75 and £M 7.35, it implies a substantial capital expenditure amounting to as much as £M 9.8 if a spare system is included.

Neglecting all operating costs, this initial outlay could be more than the sum needed to re-engineer existing ground stations and so for economic reasons alone, the use of balloons would need very careful consideration.

TABLE 2

Ground Station Transmission

ADVANTAGES
Easily switched for either regional or local broadcasting.
High reliability with breakdowns only affecting a small area.
Unlimited programme hours.
Low annual running costs.
DISADVANTAGES
Insufficient Frequency Spectrum for effective two programme coverage.
High cost of coverage to remote rural areas.
High capital investment to complete a national network.

TABLE 3

Aircraft transmission

ADVANTAGES
Large coverage area from the moment of commissioning.
Low capital cost per head for population served.
Conserves television channels.
Inherently covers scattered communities.
DISADVANTAGES
Large areas are subject to co-channel interference.
A greater degree of international co-ordination is required.
Inferior reliability.
Restricted daily operating times.
High annual running costs.

6. Conclusions

After studying the experience of others, it does appear that the electrical and aeronautical disciplines could be successfully combined. How the application of airborne techniques modifies the established understanding of propagation at Band III and whether editorial limitations, together with the risk of total programme loss are acceptable, are questions that all require clarification before preparing any final specification. It is realised that the recommended radiated e.r.p. of 28 kW may be too ambitious in terms of aircraft power supplies. The provision of 53 dB (μV/m) at the service fringe forms the minimum field strength that will give a satisfactory grade of picture and although may not be protected from co-channel interference for quite so long as the 55 dB (μV/m) assumed, would reduce the power to the more acceptable level of 18 kW. The final choice of e.r.p. would depend on international negotiations, reception quality at cluttered sites near the limit of service, and to what extent signal variation was reduced by the break up of anti-phase foreground reflections compared with the Lasham results. A second series of reception experiments would therefore be necessary in various urban environments, to resolve a number of remaining problems and unknowns.

With reference to the relative costs quoted for complete v.h.f. systems over a ten year period, there is little difference between ground stations and ex-airline Bristol Britannias. Bearing in mind there are likely to be difficult regulatory and international planning problems, the long term choice favours a conventional terrestrial network. However, the use of aircraft may be economic on a temporary basis. As an aid to re-engineering, the 405-line monochrome transmissions could be transferred to aircraft while ground stations are rebuilt, thereby avoiding the need to fully maintain an established service. The best financial return, if all the administrative constraints on v.h.f. airborne transmission could be overcome, endorses the use of captive balloons (T.COM.). Nevertheless, this would still be more expensive than modifying existing buildings and masts for a new 625-line colour service.

7. Acknowledgements

The authors acknowledge the unfailing co-operation of the Royal Aircraft Establishment, Farnborough, including members of the Radio Department, Cove and Lasham measuring stations. Also the valuable discussions with Westinghouse International Defence and Public Systems Corporation and Shackleton Aviation Ltd., London, are gratefully acknowledged.

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* This work has also been undertaken for v.h.f.

APPENDIX I

Flight test details

1.	Course of aircraft	:	Farnborough–Lasham–Dorchester–Lyme Bay
2.	Maximum duration of flight	:	2½ hours
3.	Number of flights	:	2
4.	Maximum altitude	:	10,000 ft.
5.	Type of aerial	:	Folded monopole
6.	Radiation pattern	:	Nominally omni-directional
7.	Polarisation	:	Vertical
8.	Type of emission	:	Unmodulated Carrier Wave with 5 second interruptions every 15 minutes for indentification purposes.
9.	Frequency	:	224 MHz
10.	Effective radiated power	:	Not exceeding 1 watt

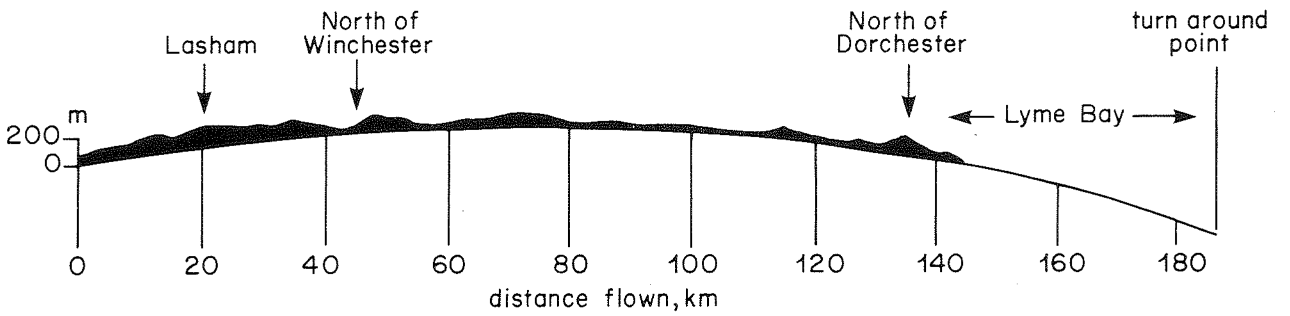

Fig. 12 - Flight path profile

APPENDIX II

Roughness criteria

The reflection coefficient used in calculating the value of ground reflected signals only applies when the reflecting surface is smooth. A surface may be considered rough if the variations in surface height are sufficient to cause a variation in path length of more than an eighth of a wavelength.

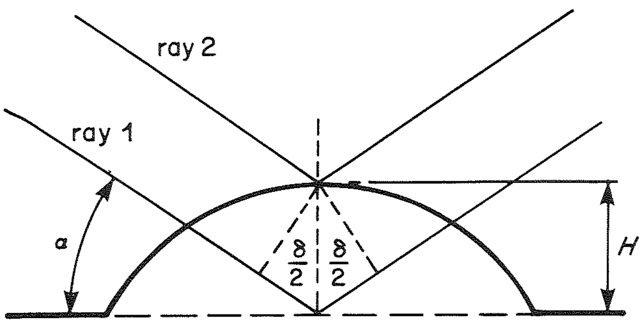

Fig. 13 - Surface roughness

In Fig. 13 the path difference between ray 1 and ray 2 is δ and α is the angle of incidence. H is the variation in the surface height. From the above definition of roughness

$$\delta < \frac{\lambda}{8}$$

hence

$$2H \sin\alpha < \frac{\lambda}{8}$$

and

$$H < \frac{\lambda}{16 \sin\alpha}$$

For large transmitting aerial heights and small receiving aerial heights the ground distance between transmitter and reflection point d is approximately equal to the distance between transmitter and receiver D. See Fig. 14.

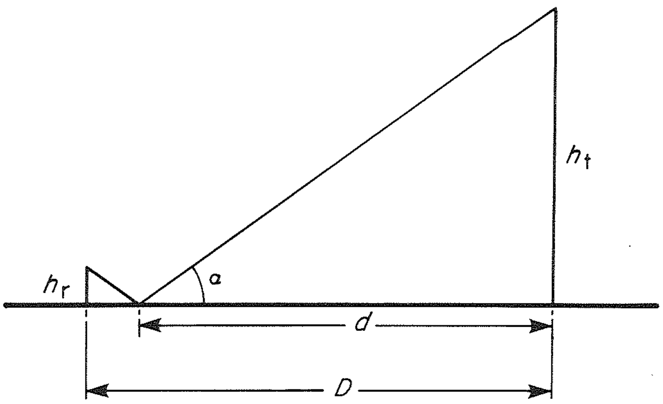

Fig. 14 - Reflection point position

hence

$$\sin\alpha \triangleq \frac{h_t}{\sqrt{h^2_t + D^2}}$$

and

$$H < \frac{\lambda\sqrt{h^2_t + D^2}}{16h_t}$$

It follows that with a transmitter height of 9,500 ft and a ground distance of say 6·5 km, the surface roughness at a frequency of 224 MHz must be less than 20 cm for the ground to be considered smooth.

APPENDIX III

Cost comparison (valid January 1976)

Aircraft transmission

	Items	Totals
Capital		
Aircraft:		
Three second-hand Britannias	£175,000	£525,000
Airborne equipment for two programmes:		
Two 5 kW vision/sound transmitters plus reserves	£300,000	
Transmitting aerial	£50,000	
Link receiver and aerial	£25,000	
Telemetry, etc.	£5,000	
	£380,000	
Equipment for three aircraft		£1,140,000
Link ground equipment per site:		
SHF transmitters	£30,000	
Aerials and support structures, buildings, etc.	£20,000	
	£50,000	
Equipment for two ground bases		£100,000
		£1,765,000
Cost to each organisation if shared equally between the BBC and IBA	£880,625 (Say £M 0·88)	
Revenue (Expenditure)		
Aircraft:		
Annual servicing costs for a Britannia	£65,000	
Annual servicing costs for three Britannias		£195,000
Annual operating costs for a Britannia, airborne 10 hours per day, at £450 per hr.	£1,642,500	
Annual operating costs for two Britannias		£3,285,000
		£3,480,000

	Items	Totals
Revenue (Savings)		
Overheads:		
Public electricity supply charges for existing two programme v.h.f. ground station network, including maintenance and valves	£400,000	£3,080,000
Net revenue cost to each organisation if shared equally between the BBC and IBA	£1,540,000 (£M 1·54)	

Ground station transmission

Capital		
Transmitters/aerials:		
Re-engineering costs quoted in 1972 for one programme only.	£4,000,000	
Add 50% for inflation and disposal of old equipment to obtain current cost		£6,000,000
Less 25% for possible use of existing aerials	£1,500,000	£4,500,000 (£M 4·5)
Revenue (Expenditure)		
Overheads:		
Annual public electricity supply charges for new single programme v.h.f. ground station network, including maintenance and valves.		£200,000 (£M 0·2)

APPENDIX IV

Approximate costs for about 90% coverage of the United Kingdom with one programme
(Costs to the viewer have been ignored)

COST	GROUND	AIRCRAFT 8 hr. transmission per day (1)		BALLOONS		SATELLITES	
(SOURCE)	(a) VHF *(BRITISH)*	(b) VHF (2) 26,000′ level *(BRITISH)*	(c) SHF (3) 68,000′ level *(GERMAN)*	(d) VHF (2) 15,000′ level *(AMERICAN)*	(e) SHF 76,000′ level *(FRENCH)*	(f) VHF	(g) SHF (6) *(TAC–1972–P49)*
CAPITAL	£M 25 (5)	£M 0·88	Charges on capital included in revenue	£M 4·9	£M 100 total		£M 38
COSTS (per annum)	£M 0·5(7)	£M 1·54	£M 6·38	£M 0·1(8)			£M 0·38
TOTAL COST FOR 10 YEARS USE	£M 17·5(9)	£M 16·28	£M 63·83(4)	£M 5·9	> £M 25(10)		£M 41·75

(1) The 8 hours transmission cost also includes two additional hours flying time to arrive/depart flying zone.
(2) Cost to a single organisation if a two programme network was shared equally between two broadcasting authorities.
(3) Estimate by Institut fur Aerodynamik Braunschweig and exchange rate 4·7 DM/£.
(4) The cost would be reduced (but not pro rata) if shared by more than one authority.
(5) Very rough estimate including £M 7 for r.b.l. equipment and programme links.
(6) Single programme satellite for individual reception.
(7) 50 stations with 70 staff at an average salary of £4,000 p.a. plus maintenance, rates and electricity costs.
(8) Very rough estimate.
(9) It is assumed that the equipment has a 20 year life span.
(10) Assuming 4 programme capacity.

Figures based on:

(a) and (b) UK/BBC estimate
(c) Com.T(K) 305
(d) T.COM. Corporation literature
(e) PAGASE proposal for 30 balloons.
(g) UK Television Advisory Committee documents (Papers of the Technical Sub-Committee, 1972).

HR/VY